

# Web-oriented GIS system for monitoring, conservation and law enforcement of the Brazilian Amazon

Carlos Moreira Souza Jr. • Kátia Pereira • Victor Lins •  
Sanae Haiashy • Daniel Souza

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**Abstract** A web GIS (WGIS) system for the Brazilian Amazon, named ImazonGeo and based on open source and public domain data, is presented. ImazonGeo was built following three principles. First, the system is based on Spatial Data Infrastructure architecture and web interface built using free software and public domain data. Second, we went beyond visualization of maps and spatial queries by providing information obtained with spatial analysis models. To do that, we designed a database that stores the results of previously defined spatial analyses and developed customized reports and query tools to facilitate fast access of information by end-users. Finally, the system is application-oriented in the areas of forest monitoring, conservation and forest law enforcement, meaning that it aims to contribute to support the protection of Brazilian Amazon forests. We illustrate these principles by presenting ImazonGeo's technology, architecture, content and tools. Moreover, we present two successful cases to demonstrate how the system is being used. We conclude the paper discussing the challenges and potential solutions to turning our WGIS-SDI system into an internet hub of geo-information about the Brazilian Amazon.

**Keywords** Amazon • Conservation • Monitoring • Spatial data infrastructure • Web GIS

## Introduction

The Brazilian Amazon rainforests, hereafter referred to as the Amazon, covers an area of 4.1 millions square kilometers, harboring 40% of the global tropical forests with rich biodiversity of plants and animals, and a vast array of environmental services and natural resources (Foley et al. 2007). This region has been threatened by deforestation and selective logging over the past 50 years. Currently, about 20 percent, i.e. 800 thousand square kilometers (Inpe 2009), of the original Amazon rainforests have been converted to cattle ranching, large scale mechanized agriculture, small scale slash-and-burn agriculture, tree plantations and other forms of land use (Laurance et al. 2004), (Fearnside 2005). Moreover, selective logging and forest fires have impoverished these forests by reducing carbon stocks, causing local tree species extinction and decreasing animal biodiversity by hunting (Asner et al. 2005; Nepstad et al. 1999, Peres et al. 2006). The pattern of economic and human development has been well documented, showing slight improvement after the deforestation process followed by a decline a few decades later with the depletion of forest resources. This pattern follows a boom-and-bust cycle and has been demonstrated in the scientific literature (Schneider et al. 2002).

A large amount of spatial and aspatial information on human footprint, biodiversity, infrastructure and socioeconomic and biophysical variables (i.e., soil and forest types, biomass, rainforest, topography, among others) is available for the Amazon region from different sources. For example, the National Research Space Agency (Inpe – *Instituto Nacional de Pesquisas Espaciais*) provides spatially explicit deforestation polygons for the Brazilian Amazon on an annual basis (Inpe 2009) and on fire hot spots. Socioeconomic information on commodity prices, demog-

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SI: Spatial data infrastructures for the Amazon: a first step towards a Global Forest Information System

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C. M. Souza Jr. (✉) • K. Pereira • V. Lins • S. Haiashy • D. Souza  
Instituto do Homem e Meio Ambiente da Amazônia – Imazon,  
Caixa Postal 5101,  
Belém, PA, 66613-397 Brasil  
e-mail: souzajr@imazon.org.br

raphy, population growth, gross internal revenue, among others, and thematic maps (i.e., vegetation, soil) are available from the Brazilian Geography and Statistics Institute (IBGE—*Instituto Brasileiro de Geografia e Estatística*). Additionally, several data layers and satellite imagery data sets are available through Web Map Server (WMS) from different sources (i.e., NASA, Google, among others)

These types of spatial and attribute information described above has been used as a basis for formulating and analyzing environmental and socioeconomic policies for the Amazon region, such as the impact of building new roads (Laurance et al. 2001; Fearnside 2002); evaluating the effectiveness of protect areas for conservation of biodiversity (Rylands and Brandon 2005; Reid and De Sousa 2005), controlling deforestation by integrating rural property boundary and deforestation data layers (Fearnside 2003), zoning areas for sustainable forestry (Verissimo et al. 1998; Verissimo et al. 2002) and modeling future deforestation trends in the region (Laurance et al. 2001; Soares-Filho et al. 2006). Geographic Information Systems (GIS) have had a crucial role in combining and analyzing information for these socioeconomic and environmental applications. The ability to organize and access large databases and analyze and report results of spatial and attribute queries has positioned GIS as one of the key technologies for understanding the status and predicting the fate of the Brazilian Amazon.

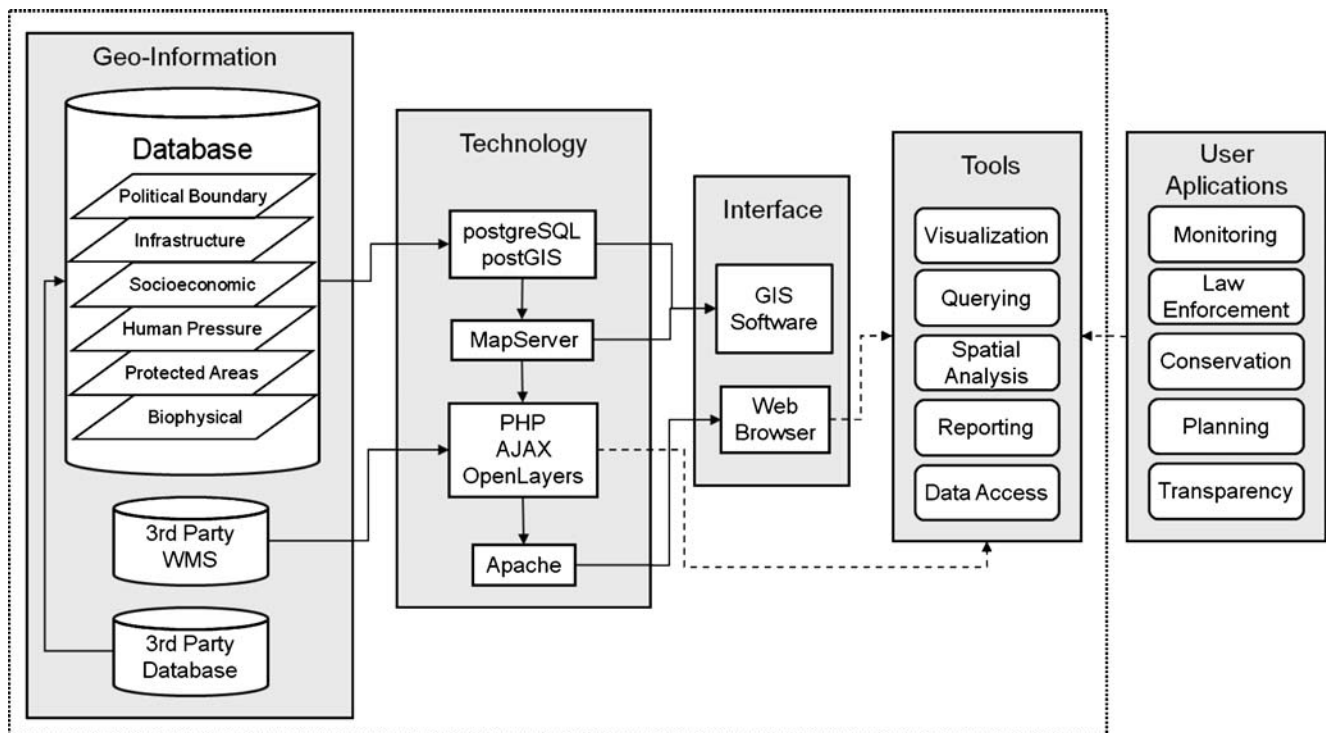
More recently, Web-based Geographic Information Systems (WGIS) have become available to facilitate access to digital maps and spatial model results. This represents a tremendous step in democratizing access to geographic information among different users. WGIS systems for the Brazilian Amazon have spread rapidly on the internet with most of them focused on visualization of database contents and attribute query results. Existing WGIS systems for this region lack tools for spatial analysis—using different data sources—and quick access to reports containing maps, graphs, text and tabular information. However, there are challenges to implementing such WGIS tools. First, the WGIS database and metadata must be updated frequently to make it relevant to end-users interested in monitoring and conversation applications. For example, information on fire and deforestation alerts exists in a daily and monthly basis, respectively, making database update a requirement. Second, end-users require results of spatial analysis such as defining deforestation hot spots in protected areas, municipalities, and other geographic units. This type of application requires performing spatial analysis on-the-fly which imposes a high demand for internet server to deliver the query results. Third, there is the requirement to understand user needs about the information necessary to support their

applications. Therefore, developing a WGIS requires a detailed survey about the demand for spatial information among several group of users working on monitoring and conservation fields. Finally, WGIS must be easy-to-use by end-users which usually do not possess background on GIS and spatial analysis. For example, some users just need to receive a deforestation alert report with the location of the event and ancillary information to access the area. This type of task must be performed by providing only an e-mail address to receive the alert report.

The advent of Spatial Data Infrastructure (SDI) shed lights on how to overcome these challenges. Wikipedia, another powerful tool for democratizing information, defines SDI as ‘... a framework of spatial data, metadata, users and tools that are interactively connected in order to use spatial data in an efficient and flexible way’. (Groot 1997) highlights the main purpose of SDI as being to reduce user effort, time and financial resources needed to access and use geographic information. In this paper, we present a WGIS system developed for the Brazilian Amazon region, named ImazonGeo ([www.imazongeo.org.br](http://www.imazongeo.org.br)), whose aim is to go beyond visualization of static data layers by focusing on user needs for application in monitoring, environmental law enforcement, conservation and in increasing transparency of governmental information. To demonstrate how ImazonGeo works, we first present ImazonGeo SDI architecture, database, technology and tools to facilitate access to information resulting from spatial analysis. Next, we demonstrate ImazonGeo’s strengths with two examples of applications: i) monitoring deforestation and fires; ii) law enforcement of Protected Areas. Finally, we conclude this paper with a discussion of future developments of ImazonGeo and our strategy for engaging end-users to effectively take advantage of this SDI WGIS system.

### ImazonGeo SDI

ImazonGeo SDI is made up of five components: i) Geo-information; ii) Technology; iii) Interface; iv) Tools, and v) User applications (Fig. 1). These components are integrated to respond to three specific objectives of the system. First, develop a robust database to facilitate access to relevant information the Brazilian Amazon and of results of complex spatial analysis. Second, develop an affordable system based on public domain geo-information databases and software technologies. Third, provide relevant applications, based on simple and intuitive tools, to support monitoring and conservation of the Brazilian Amazon forests. The system components and presented in detail below.



**Fig. 1** ImazonGeo web portal spatial data infrastructure is composed of geo-information, technology, web interface, tools and applications. The SDI diagram shows how these components are made and how they integrate with each other

### Geo-information

The core component of ImazonGeo is its geo-information database, which is made up of the main database and third party databases (Fig. 1). The data layers and attributes of ImazonGeo come from different sources and were carefully selected to enable reporting of human pressure (i.e., deforestation, fires, socioeconomic drivers and infrastructure) for states, municipalities, Protected Areas and Agrarian settlement spatial units or polygons. There are two classes of third party databases. The first are those databases accessed only by WMS requests, and include background layers such as satellite imagery, topography, and basic cartographic information (i.e., roads, cities, rivers, among others). The second class of third party databases provides geo-information to be stored and organized into the main database of ImazonGeo. The main database was organized into six information categories: political, infrastructure, socioeconomic, human pressure, protected areas and biophysical, which are described in detail below (Table 1). We also make reference to the source of these data layers and attribute data, and to their associated metadata when available.

The political maps available in the main database are the state and municipal seats and boundaries (IBGE, Table 1). Each state and municipality has a unique identifier (ID) that allows them to be unequivocally located and to perform map

algebra with a variety of maps stored into the main database. Additionally, the political ID of these polygons is used to link them to their corresponding socioeconomic information.

The Protected Areas category is composed of maps of federal and state Conservation Units and Indigenous Lands. Users can identify any protected areas by name, type, state and municipality, and access attribute information on the date of creation, the tenure status, the size of the area declared in the decree of creation and calculated by ImazonGeo using GIS tools. The main source of maps for the Protected Areas is ISA (*Instituto Socioambiental*) a Brazilian non-governmental organization dedicated to keeping information about indigenous lands and territories of Brazil updated (Table 1). We have also complemented the maps of protected areas, particularly at the state level, and compiled all the official documents about creation of the Protected Areas using different sources from federal and state agencies (Table 1). The total amount of land in the Brazilian Amazon in the Protected Areas category encompasses 42% of the Brazilian Amazon. We have also included the Military Areas, which account for less than 1.0% of the Brazilian Amazon territory in this category of maps.

Private lands located outside the boundaries of Protected Areas belong to the Land Tenure information category made up of African-Brazilian lands, agrarian reform settlements and privately owned lands. The information on private properties is available only for a small portion of

**Table 1** Geo-information content of ImazonGeo by category; types of data layers point to the source and web location

Geo-information Category	Data Layer	Scale	Source	http
Political Boundary	Municipality	1:1000.000	IBGE	<a href="ftp://geofp.ibge.gov.br/./mapas/malhas_digitais">ftp://geofp.ibge.gov.br/./mapas/malhas_digitais</a>
	Municipal Seat	1:1000.000	IBGE	<a href="ftp://geofp.ibge.gov.br/./mapas/">ftp://geofp.ibge.gov.br/./mapas/</a>
	States	1:1000.000		
	State capital	1:1000.000		
Protected Areas	Federal Conservation Units	1:1000.000	Isa	<a href="http://www.socioambiental.org">www.socioambiental.org</a>
	State Conservation Units	1:1000.000	Imazon	<a href="http://www.imazon.org.br">www.imazon.org.br</a>
	Indigenous Lands	1:1000.000		
	Military Areas	1:1000.000		
Land Tenure	African Brazilian Lands	1:1000.000	IBGE	<a href="ftp://geofp.ibge.gov.br/./mapas/">ftp://geofp.ibge.gov.br/./mapas/</a>
	Agrarian reform settlements	1:250.000	INCRA	<a href="http://www.incra.gov.br/portal/">www.incra.gov.br/portal/</a>
Infrastructure	Roads	1:50.000	Imazon	<a href="http://www.imazon.org.br">www.imazon.org.br</a>
	Ports	1:1000.000	IBGE	<a href="ftp://geofp.ibge.gov.br/./mapas/">ftp://geofp.ibge.gov.br/./mapas/</a>
	Airports	1:1000.000		
	Dams	1:1000.000		
Biophysical	Rivers	1:1000.000	IBGE	<a href="ftp://geofp.ibge.gov.br/./mapas/">ftp://geofp.ibge.gov.br/./mapas/</a>
	Vegetation			
	Amazon Biome	1:2500.000	WWF	<a href="http://www.wwf.org.br/index.cfm">http://www.wwf.org.br/index.cfm</a>
	Topography – Google Physical		Google	available in the API OpenLayers
Socioeconomic	Slaughter Houses	1:1000.000	Imazon	<a href="http://v2.imazongeo.org.br/doc/downloads.htm">v2.imazongeo.org.br/doc/downloads.htm</a>
	Logging Centers	1:1000.000		
	Mining operations	1:1000.000	DNPM	<a href="http://www.dnpm.gov.br/">http://www.dnpm.gov.br/</a>
	Municipal information	–	IBGE	<a href="http://www.ibge.gov.br/cidadesat/">www.ibge.gov.br/cidadesat/</a>
	States information	–	IBGE	<a href="http://www.ibge.gov.br/estadosat/">www.ibge.gov.br/estadosat/</a>
	Mining reserves	1:1000.000	IBGE	<a href="ftp://geofp.ibge.gov.br/./mapas/">ftp://geofp.ibge.gov.br/./mapas/</a>
Human Pressure	Deforestation – Prodes	1:100.000	INPE	<a href="http://www.obt.inpe.br/prodes/index.html">www.obt.inpe.br/prodes/index.html</a>
	Deforestation – Deter	1:500.000	INPE	<a href="http://www.obt.inpe.br/deter/">www.obt.inpe.br/deter/</a>
	Deforestation – SAD	1:500.000	Imazon	<a href="http://v2.imazongeo.org.br/doc/downloads.htm">v2.imazongeo.org.br/doc/downloads.htm</a>
	Fire hotspots	1:1000.000	INPE	<a href="http://sigma.cptec.inpe.br/queimadas/">sigma.cptec.inpe.br/queimadas/</a>

the Brazilian Amazon. For this reason, we have not included this map information in ImazonGeo (Table 1).

The Infrastructure information available in the database includes roads, ports and airports. Road maps come from IBGE which includes the so-called official roads, and from our research group, which hand-digitized roads built by loggers, gold miners and land speculators (Brandão and Souza 2006). The total unofficial road network adds another 300 thousand kilometers and is intimately linked to deforestation and logging, outperforming the length of official roads threefold. We have also included maps of ports, airports, dams, power line grid and gas pipelines within the Infrastructure geo-information category (Table 1).

The Biophysical category includes information on Rivers, Vegetation types, the boundary of the Amazon Biome and topography. This category of maps can grow easily but we decided to initially maintain only the key information for the current applications available into ImazonGeo (Table 1).

There are several socioeconomic information and maps currently available in ImazonGeo. We have prioritized maps and socioeconomic indicators that are highly correlated with deforestation (Ewers et al. 2008). The maps include cattle ranching centers, as represented by slaughterhouse locations, logging centers and mining operations and reserves. Socioeconomic attribute information by municipalities and states is also available within this category, including GDP (Gross Domestic Product), population size, and human development indicator (Table 1).

The final geo-information category is e Human Pressure. This category is represented by maps of deforestation and active fire hot spots from different sources. Users of ImazonGeo have three sources of deforestation maps. Prodes and Deter are from Inpe and SAD from Imazon. Prodes is based on the interpretation of Landsat images (pixels size of 30 m) and is available in digital map format for 2000 through 2008 on an annual basis. Deter (*Sistema de Detecção de Desmatamento em Tempo Real*) provides

deforestation polygons based on Modis (Moderate Resolution Imaging Spectroradiometer; pixel size of 250 m) on a monthly basis. SAD (*Sistema de Alerta de Desmatamento*) also based on Modis, but using a different algorithm, detects deforestation on a monthly basis as well (Souza et al. 2009). Regarding active fires, ImazonGeo collects and organizes in its database nineteen sources of information obtained from different remote sensing satellites and processed by other groups (GOES, NOAA, Terra, Aqua, and Meteosat). Because these fire maps are updated on a daily basis, a computer software robot was built to access the repositories of these maps, download and organize them into our geo-database. The robot is a simple script program that accesses database through http (hypertext transfer protocol), fetches the data to our server and organize them in our database and perform pre-defined spatial analysis.

### Technology

The ImazonGeo logical infrastructure is made up of various open source technologies that were integrated in developing the system (Fig. 1). Storage and management of geospatial information is done with the PostgreSQL software—that functions as an Object-Relational Database Management System (ORDBMS)—and its postGIS extension that allows the use and storage of map and image objects. We also utilized MapServer to visualize maps and images stored in the database on the web. MapServer is also a free software and serves as a development environment for constructing spatial applications on the internet. Regarding hardware technology, ImazonGeo database runs in a server with a quad core processor. To make the access of spatial queries faster, we saved results in cache what requires large amount of disk space to store these results.

The ImazonGeo web interface was essentially written with PHP dynamic language due to its speed and portability. We also used AJAX (Asynchronous Javascript And XML) techniques, making use of technologies such as Javascript and XML provided by most internet browsers, to make pages in the system more interactive with the user, utilizing asynchronous information requests.

As the front-end for ImazonGeo, we used the open source JavaScript library called OpenLayers, a tool for exhibiting spatial data on web pages. OpenLayers has an API (Application Programming Interface) for constructing web-based applications. Openlayers is utilized for exhibiting maps and images from the ImazonGeo database accessed using MapServer. It also allows maps to be loaded from other data sources such as Web Map Service, Web Feature Service, Google Maps and others. For example, on ImazonGeo as a background we used the Google satellite

images and location labels from ImazonGeo WMS Google Hybrid. The user may use other layers available on ImazonGeo as background.

Internet Access service via web browsers is done with the Apache web page server, which is the most successful free web server, besides being one of the most used ones around the world. ImazonGeo also provides access to shapefiles for downloading information processed by Imazon. We also make available for download socioeconomic information from states and municipalities in the Brazilian Amazon from 1990 to 2007 (IBGE, Table 1), present in reports on states and municipalities.

### Interface

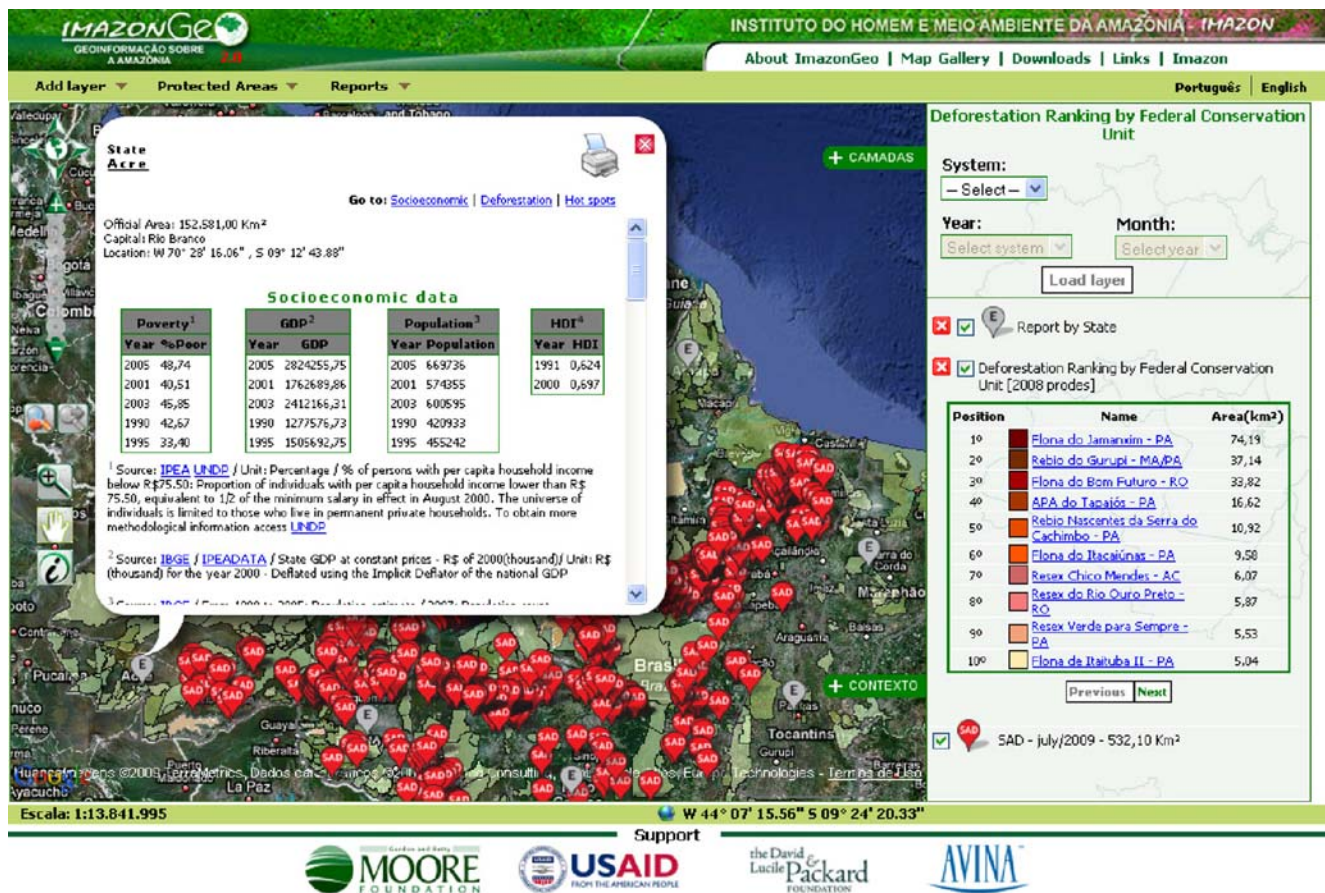
Access to ImazonGeo resources may be done in two ways: through a web browser, or via GIS software with resources for a WMS (MapServer) connection or with a PostgreSQL database. In the first access modality, web browser, the user of the system has available all of the tools that the system offers. In the second form of access, via WMS or connection with the database, it is possible to access the ImazonGeo database with GIS software that enable that type of connection, allowing the user to do analysis or consult spatial data in another architecture with the information available in the PostgreSQL database.

### Tools

ImazonGeo user interaction is facilitated by easy-to-use tools that allow visualizing, querying, conducting spatial analysis and reporting the results. These tools can be accessed through menus, fields, markers, pop-ups, buttons, layer selections and hyperlinks (Fig. 2). There are four major environment areas in the website. In the upper right position users have access to hyperlinks to provide information about ImazonGeo, galleries of maps, downloads of maps, links to data providers and to the Imazon website. Below the hyperlinks follow menus to access maps of human pressure and results of spatial analysis and applications (Fig. 2).

All types of maps can be visualized in the map view area, directly below the menu area (Fig. 2). There users will find tools to pan, zoom and get attribute information on geographic features. On the right of the map view there are two areas containing information that users have accessed through menus. The top area has table fields that allow users to refine spatial attribute queries. At the bottom, users can find different objects such as geographic markers, text objects with results of local queries, and legends of maps accessed through the main menu, among other types of objects.





**Fig. 2** AmazonGeo web interface showing an example of visualization interface and tools to facilitate user accessibility to geo-information. In this example, users have fast access to a report embedded in a pop-up window containing socio-economic, deforestation and fires statistics

In Fig. 2, we present some examples of visualization and objects created using tools available in AmazonGeo. By selecting the State option in the report menu, users will bring report marker with a balloon with a letter 'E'. When clicking in one of the nine 'E' balloons, representing each of the Brazilian Amazon states, users will have a pop-up report containing socio-economic information available in the database and results of spatial analysis (scrolling down the pop-up window) of deforestation and fires in that particular state. In this pop-up report window, it is possible to download the table contents or print the report (Fig. 2). This represents a tremendous advance in providing relevant attribute and spatial information to end-users following a few clicks on the mouse. More examples of how users can use AmazonGeo's tools to access information will be presented in the application section.

## Applications

AmazonGeo was conceived to be application oriented, meaning that end-users would have easy-to-use tools to

by States (gray balloons), the ranking of most deforested Federal Protected Areas as detected by Prodes in 2008, and the location of deforestation alerts as detected with SAD (red balloons)

access organized and well-structure databases containing relevant information to support monitoring, law enforcement and conservation applications. Additionally, the system aims to contribute towards transparency in governmental agencies by facilitating access and making their information readily accessible through the internet (Fig. 1, Table 1). As our database expands and new spatial analysis and tools become available, other applications can be incorporated into the system. However, for the purpose of this paper, we will focus on two cases in order to demonstrate how AmazonGeo can be used to monitor the Brazilian Amazon and to support law enforcement of Protected Areas.

### Case 1: Monitoring deforestation and fires

In this application example, we gathered and organized all publicly available information about deforestation and active fires in the Brazilian Amazon. Next, we selected spatial analysis that can generate key (geo-) information to end-users and built quick reports to facilitate access to these spatial analyses. There are several sources of deforestation

and fire maps for the Brazilian Amazon. For the later, we include maps produced by the National Space Research Institute of Brazil (Inpe), which produces annual (Prodes @ <http://www.obt.inpe.br/prodes/>) and monthly (Deter @ <http://www.obt.inpe.br/deter/index.html>) deforestation maps and statistics. Additionally, we included monthly deforestation information generated by Imazon through its Deforestation Alert System (SAD) (Souza et al. 2009). For fire maps, we included 19 ‘hot pixel’ products derived from different remote sensors and institutes (Table 1).

Several types of information are available at ImazonGeo to users interested in monitoring deforestation in the Brazilian Amazon. One example is the map of deforested areas generated by each source of information (i.e., Prodes, Deter or SAD). Having these types of map information easily available through the internet represents a major step towards understanding human pressure by deforestation on the Brazilian Amazon. However, end-users are mostly interested in statistics and maps obtained by combining deforestation maps with other types of maps. For this reason, we developed three types of spatial analysis and tools to supply this type of user demand. The first one is the deforestation ranking, which can be obtained by state, municipality, rural settlement, indigenous lands, and state and federal conservation units. Figure 3 has results of this spatial analysis showing a map of the top ten most deforested municipalities in the Amazon as detected by SAD in October 2004. Users can choose to show the ten next most deforested municipalities by clicking the ‘next’ button below the map legend. Additionally, all of the deforestation locations detected by SAD in this period are marked with balloons in the map view area. The second type of spatial analysis of deforestation is the classification of deforestation by size of the area deforested per state, municipality, rural settlement, indigenous lands, and state and federal conservation units. The last one is the list of the largest deforested areas in the Amazon region (by source of information). These two types of geo-information can be useful in supporting field operations to enforce environmental law in this region (Fig. 3).

Regarding monitoring of active fires, users can also generate maps, ranking and classification by the number of fires per state, municipality, rural settlement, indigenous lands, and state and federal conservation units. All public sources of active fire information for the Brazilian Amazon region are available in ImazonGeo. Figure 3 shows the location of active fires as detected by Terra-Modis. Likewise deforestation, statistics and reports of fires are available to support monitoring operations in this region.

#### Case 2: forest law enforcement of protected areas

In the Amazon, the slow implementation of Protected Areas and the low effectiveness in applying the environmental

crimes law leave such areas vulnerable to the advance of deforestation and predatory logging. This results from delays in detecting illegal deforestation and the lack of material evidence to characterize this type of environmental crime. To overcome those problems, we have developed a partnership with the Brazilian federal environmental agency (Ibama) and public prosecution offices which allowed us to implement a web application to enable timely monitoring of illegal deforestation and fires in Protected Areas in the Amazon.

Monthly monitoring of deforestation in the Protected Areas is done using SAD developed by Imazon. This system uses images from the MODIS sensor (Moderate Resolution Imaging Spectroradiometer), which has the capacity to automatically detect deforestation increments greater than 10 hectares monthly. After detection, the deforestation areas (polygons) are transferred to Imazon-Geo. In the ImazonGeo intranet environment, the deforestation polygons in Protected Areas are audited and validated using higher spatial resolution satellite images (Landsat at 30 m pixel size and CBERS with 20 m). This procedure is necessary for unequivocal confirmation of illegal deforestation detected by SAD, which can inform bringing of administrative and court proceedings by the Federal Public Prosecution Service in the State of Pará (MPF-PA), a partner institution in this project. Next, the validated deforestation polygons are incorporated into representations that are official documents forwarded to the MPF-PA (Fig. 4). Each representation has summarized information about the name and type of Protected Area deforested, date of creation, municipality, state and location and estimate of the deforested areas, together with satellite images utilized in detection and validation.

From August 2007 to December 2008, 389 squares kilometers were deforested in Protected Areas in square kilometers Pará. Of those, 182 square kilometers were forwarded to the MPF in the form of representations ( $n=145$ ) distributed in 21 Federal Protected Areas. Deforestation with representation occurred in nine Indigenous Lands, Nine Sustainable Conservation Units and three Full Protection Conservation Units. The majority of deforestation was concentrated in the “Terra do Meio” region and near the BR-163 highway, which are areas where the deforestation frontier is expanding (Fig. 3).

Based on the representations, the MPF began several actions to combat deforestation in federal Protected Areas in Pará. After one year, the great majority (82%) of cases forwarded to the MPF are still in the investigation phase. The objective of that phase is to gather sufficient proof to propose actions at both the civil and the criminal levels. To do that, information is surveyed by the MPF itself or through other agencies such as IBAMA/ICMBio, FUNAI and Federal Police. In the other 18% of cases of representations of deforestation information had not been forwarded as of



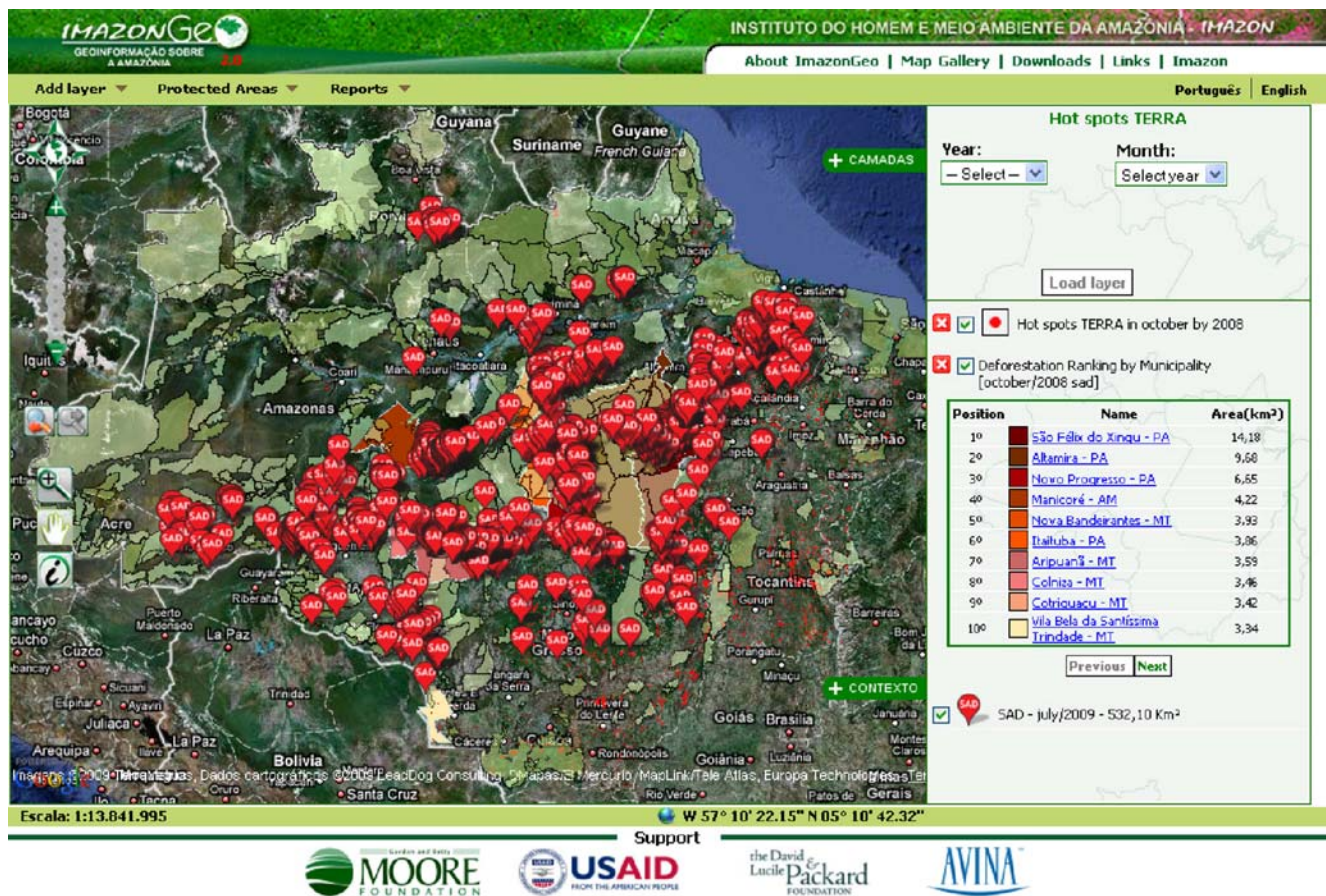


Fig. 3 AmazonGeo geo-information to support user application in monitoring deforestation and fires

December 2008. That is because those representation had been sent to MPF in October and November 2008, and there was not enough time for the MPF to generate information regarding them. That information on proceedings with the MPF-PA is fed back into the ImazonGeo database so that we can monitor those proceedings. But it is only made available to the public in general with authorization from the MPF-PA so as not to interfere with investigations.

Cases of illegal deforestation in Protected Areas that are already being judged are available on ImazonGeo for access by the general public. Up to now, the cases available are the ones being judged by Ibama (Federal Environmental Agency). The general public can access maps ranking the proceedings in Protected Areas, the classification of Protected Areas by amount of the fine in Reals, as well as information about the period when the proceeding began. Users may also access the Ibama website to obtain detailed information about the proceedings (Fig. 4).

## Discussion and conclusions

Our society is facing a new era of access to data and information with the advent of Web 2.0 (e.g., Dayton and

Thacker 2008; Hardey 2008; Tang and Waters 2005, among others). Access to geographic information has also been facilitated using the new technologies embedded in Web 2.0 and has gained rapid dissemination through WGIS systems on the internet (Su et al. 2000; Athanasis et al. 2009). As a result, WGIS has become an essential tool for SDI in many countries (e.g., Maguire and Longley 2005; Koshkarev et al. 2008); Beaumont et al. 2005; Rao et al. 2002). WGIS and SDI applications are broad, ranging from managing and planning of conservation reserves (Rao et al. 2002), to exploring biodiversity (Flemons et al. 2007), decision support (Karnatak et al. 2007), public health (MacLachlan et al. 2007; Moreno-Sanchez et al. 2006) and education (Lo et al. 2009), among many others.

In this paper, we present a new WGIS system for the Brazilian Amazon built to support forest monitoring, environmental law enforcement, conservation, and contribute to increasing transparency of governmental information, policies and actions to stop illegal deforestation and forest degradation in the region. ImazonGeo integrates and organizes data and information—in the format of maps and attributes—from several sources in a large database. This allow us generate maps, statistics and reports based on relevant spatial analyses for end users interested in these applications.



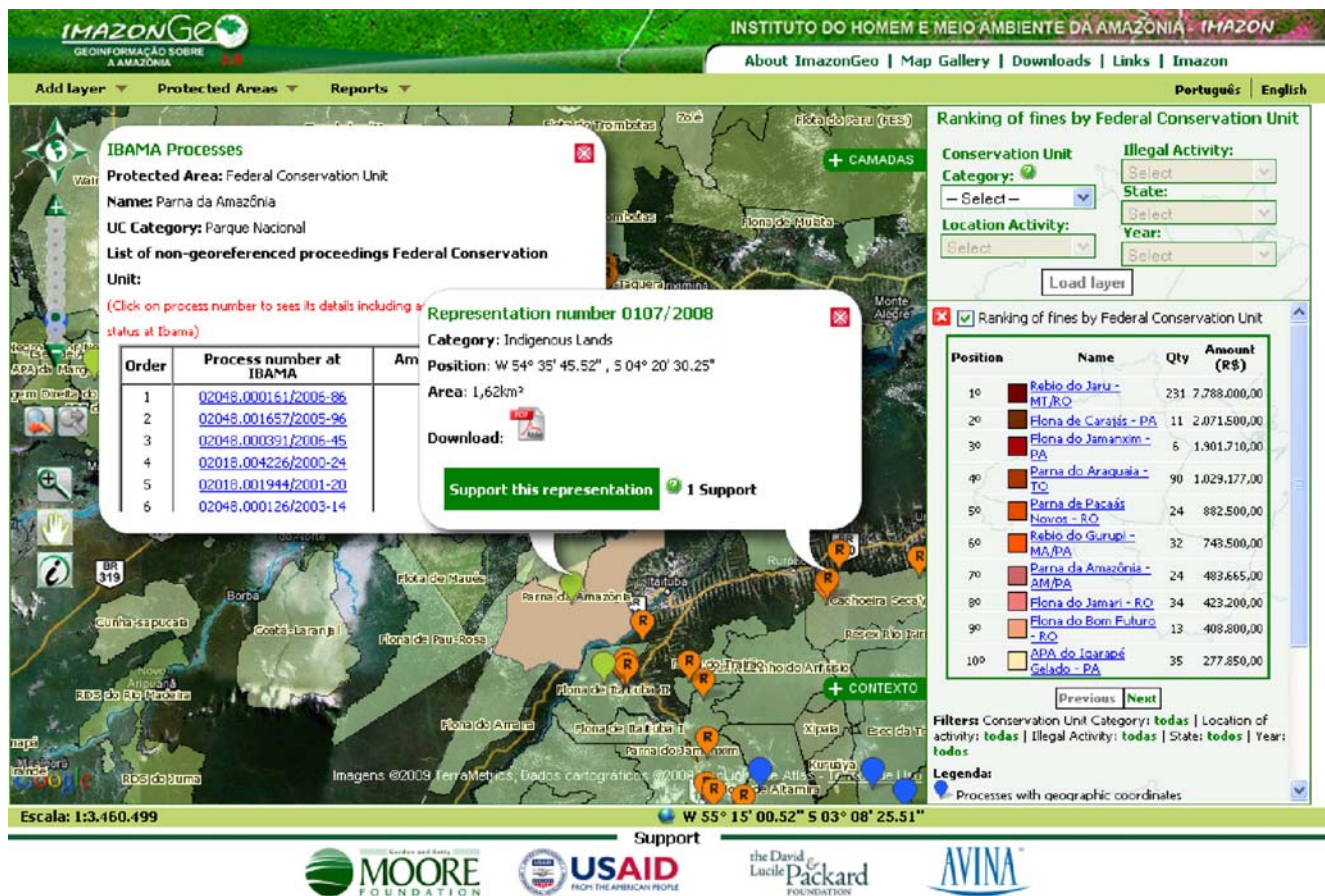


Fig. 4 AmazonGeo application to support enforcement against illegal deforestation in Protected Areas

Initial surveys of current and potential users show that the information provided by ImazonGeo is relevant and useful to their work. Users come from different organizations, including federal, state and municipal government agencies, NGOs, journalists, researchers, students and individuals. Most users are interested in the deforestation and fire alerts, reports, and data download. Since the launch of ImazonGeo in May 2007, the WGIS system had more than 19,000 accesses and more than 7,000 downloads of maps and tables. From April 2008 through April 2009, the Forest Transparency Bulletin, one of the ImazonGeo customized reports based on our deforestation alert systems and spatial analysis, had 8,394 downloads. Another indirect measure of impact is the number of articles in media vehicles (newspaper, internet, TV and radio) based on SAD and spatial analysis of deforestation pressure in the Amazon region, resulting in 527 articles published. A further positive impact of ImazonGeo was the number of illegal deforestation alerts in Protected Areas that turned into official enforcement cases with the Public Prosecution Office of Pará State, described in detail above as a successful case.

Response to ImazonGeo is positive but we are far from being a hub of geospatial information for the Amazon region. Our strategy to increase access to ImazonGeo is

multifaceted. First, we are building geo-wiki interfaces to allow users to input data and provide feedback to our system. So far, we have couple of geo-wiki tools. One is operational, consisting in the intranet interface to monitor the enforcement of actions against illegal deforestation. The other is publicly open and will allow internet users to support enforcement against illegal deforestation in Protected Areas of the Brazilian Amazon. While the first one has a limited number of users because of its restricted access, the second has a broader access and the potential to attracted millions of users.

The second strategy to increase user access to ImazonGeo is to provide short tutorials to use the tools and access information (i.e., maps, alerts, reports, statistics) and download them using the system. Even though we built easy-to-use tools and abstracted spatial analysis, by processing offline and storing results in the database, end users with no prior knowledge of GIS are overwhelmed when they try to use the system. Our experience shows that capacity-building is required to make users more comfortable using GIS tools on the web and understanding the web system content. Besides tutorials, we will develop short training and workshops targeting specific audiences to demonstrate ImazonGeo tools and applications.

The third strategy to engage users is to expand the information content of and develop new applications to ImazonGeo. As an example of new applications, we are currently developing carbon emission models from deforestation and forest degradation to provide information on carbon dioxide emissions associated with deforestation in the Brazilian Amazon. Following the current application models of ImazonGeo, the carbon emission results will be stored in the database and access to the results (through maps, statistics, reports, etc.) will be customized to fast access information.

The last strategy will focus on the development of geo-wiki interfaces to ImazonGeo and mash-ups with virtual community web systems. Currently, we have been developing a simple geo-wiki interface to ImazonGeo that will allow users to enforcement against illegal deforestation in Protected Areas of the Brazilian Amazon. Users will be able to identify cases of illegal deforestation that are being judged, send requests, as protests, to prioritize cases with the environmental agencies and courts, monitor the length of the proceedings, and receive alerts about the status of the process. We hope that this type of geo-wiki tool can engage civil society in order to accelerate the cases and bring positive pressure on the enforcement system to properly punish violators. This is important, because the application of enforcement law represents the major bottleneck to stopping illegal deforestation in the Brazilian Amazon (Brito and Barreto 2009). We have also been exploring mash-up applications with other web systems and integration of our system with mobile phone applications. For example, individuals could support conservation and protections of forest reserves by paying monthly fees and being able to monitor the status of the reserve using mobile phone.

In summary, there is no doubt that SDI and WGIS technology is mature enough to be used to support protection of rainforests through monitoring, conservation and law enforcement applications. Furthermore, the web systems developed with these technologies, including those with geo-information, are accessible to hundreds of millions of people. Engaging millions of people to protect rainforest through WGIS systems will require easy-to-use tools, education through tutorials, geo-wiki tools to make users part of the process, and geo-systems developers aware of users' needs and limitations, in order to provide reliable information.

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